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Set-up and alignment aspects of a CO_2-laserradar for applications in the field.

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ABSTRACT (UNCLASSIFIED)

The set-up of a multifunctional CW CO_2-laserradar system is described. Special attention is given to some recent modifications. They consist mainly of the addition of an acousto-optic modulator (AOM) in the local oscillator beam of the heterodyne detection system, and of the renewal of the HgCdTe detector.
The added AOM shifts the frequency, at which heterodyne detection is performed, from the previous 100 MHz to 140 MHz now. This implied that the processing electronics of the set-up also had to be adapted.
A step by step procedure for the optical alignment of the system is presented.

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SAMENVATTING (ONGERUBRICEERD)

De opzet van een multifunctioneel CW CO_2-laserradar syteem wordt beschreven. Bijzondere aandacht wordt besteed aan enkele recente wijzigingen. Deze bestaan voornamelijk uit het toevoegen van een acousto-optische modulator (AOM) in de locale oscillator beam van het heterodyne detectie systeem, en uit het vernieuwen van de HgCdTe detector.

De nieuwe AOM verschuift de frequentie, waarbij heterodyne detectie plaatsvindt, van de voorgaande 100 MHz naar 140 MHz nu. Dit impliceerde dat ook de verwerkende electronica van de opstelling aangepast diende te worden.

Een stap voor stap procedure wordt gegeven voor de optische uitlijning van het systeem.

1 INTRODUCTION

A multifunctional system has been developed and built at TNO-FEL to study various aspects of laserradar applications.
This system is based upon a CW CO_2 laser, applies external modulation to the laserbeam and incorporates heterodyne detection. Advantages of such a system comprise eye-safe operation in an atmospheric transparent window, multifunctionality regarding possible applications, and high detection sensivity.
The applications of our system that are currently demonstrated are the determination of range and velocity, and the recording of low frequency vibration spectra of targets.
To improve the performance, some modifications have been introduced into the system at the beginning of 1990. A second acousto-optic modulator has been implemented for better optical isolation of the local oscillator beam. The set-up is described in chapter 2 of this report.
The procedures for aligning the optics of the set-up had not yet been reported before. As the optical modifications also imply alterations in alignment, this report also gives, in chapter 3, a detailed manual for the optical alignment procedure. Some additional remarks are made on the cooling of the CO_2 laser, the acousto-optic modulator, and the HgCdTe detector.
Chapter 4 presents a survey of the three currently implemented system modes for measuring, after which some conclusions on the laserradar set-up are given in chapter 5.

The actual performance of our modified system is reported elsewhere. These reports, by Boetz [1] and Hebers [2], describe our experiences with the multifunctional laserradar system, both under laboratory conditions as well as during a battlefield trial.

2 DESCRIPTION OF THE CW CO_2-LASERRADAR

Most aspects of tne system have previously been described by Lerou [3], Van der Vegt [4], Bentvelsen [5], Boetz [6] and Noordermeer [7].
The complete set-up, including the laserplatform, computer equipment and processing electronics, is shown in Fig. 2.1.

Fig. 2.1 Photograph of laserradar system.

The main characteristics of the system are:

- application of heterodyne detection, for maximum detection sensitivity,
- a 6 Watt continuous wave (CW) CO_2-laser,
- the use of an acousto-optic modulator (AOM), which enables the transmitted laser beam to be modulated with any signal in a bandwidth of 20 MHz.

This report will discuss the changes that have been applied since Bentvelsen [5] described the system as it was at the end of 1989.

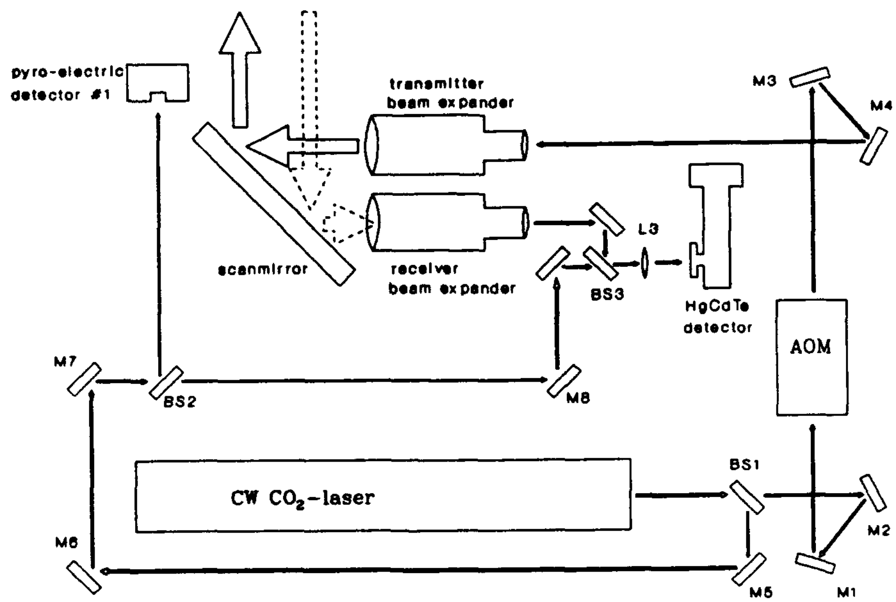


Fig. 2.2 Previous arrangement of laserplatform.

A main improvement is the addition of a second acousto-optic modulator, to produce a frequency shifted local oscillator beam (LO), resulting in an optical isolation of the LO-beam from the transmitter laser beam [8].

The changes in optical path, beam intensities, and optical components on the laserplatform will be described in section 2.1. The necessary electronic adaptions that emanated from the addition of the second acousto-optic modulator are discussed in section 2.2. These are mainly in the equipment that processes the heterodyne detector signal.

2.1 Changes in the optical arrangement

The optical arrangement, as it was before the modifications of 1990, is given in Fig. 2.2. The following modifications and additions to the set-up will be discussed:

1) acousto-optic modulator in the local oscillator (LO) beam,
2) tilting of mirrors M5 and M6,
3) addition of second pyro-electric detector (#2) in the LO beam,
4) replacement of beamsplitters BS2 and BS3,
5) addition of lens (L4) and slit (S1) to pyro-electric det. #1,
6) renewal of the SAT HgCdTe detector.

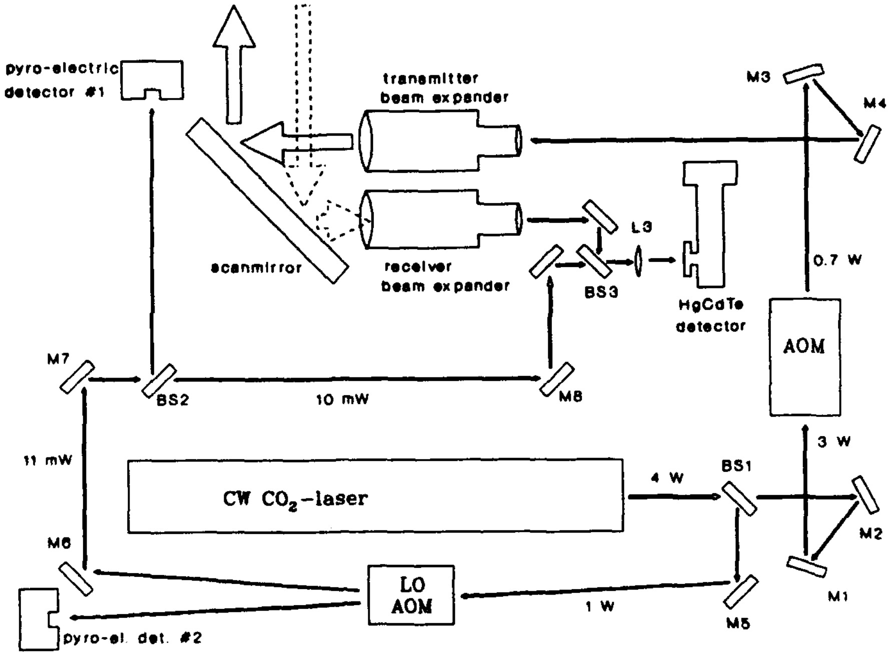


Fig. 2.3 New set-up laserplatform (with power levels).

1) In order to suppress the effects of leakage of the transmitted beam from the local oscillator, a second acousto-optic modulator has been placed in the local oscillator beam section, as depicted in Fig. 2.3. From here on we will call this element the LO-AOM.
This LO-AOM, an Isomet 1207A, deflects a 10.6 µm laser beam over a Bragg angle of 38.5 mrad when driven with a 40 MHz signal of 0 to 28 Volt. Thus the frequency of the LO beam is shifted by 40 MHz. A detailed discussion of the acousto-optic effect is given by Bentvelsen [5].
In the new arrangement, the local oscillator beam is no longer travelling parallel to the platform. The optimal placement of the LO-AOM could be calculated from the Bragg angle (38.5 mrad) and the beam heights at mirrors M5 (60 mm) and M6 (63 mm), as has been depicted in Fig. 2.4.

2) The holders of mirrors M5 and M6 are placed on thin wedges, so that these mirrors are tilted 1°. Thus mirror M5 directs the laser beam a little downwards to the LO-AOM. The beam that is deflected by the LO-AOM travels upwards to mirror M6. After reflection at M6 the beam will again travel parallel to the platform further on. The resulting beam path is shown in Fig. 2.4.

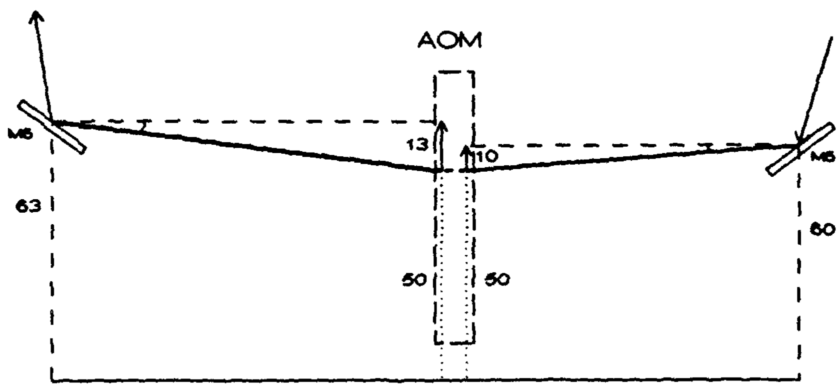


Fig. 2.4 Laser beam path between mirrors M5 and M6.

3) A second pyro-electric detector has been placed in front of mirror M6, so that the undeflected beam from the LO-AOM can be detected. We will refer to this detector as pyro-electric detector #2, in contrast to the existing pyro-electric detector #1 (located just behind the large scan mirror). The detector #2 will now be used for the stabilization of the laser.

4) The addition of the LO-AOM results in the reduction of the power of the local oscillator beam from about 1 W to 10-30 mW. To compensate for this, the beamsplitters BS2 and BS3 have been replaced. The choice of the transmittance of the new splitters is dictated by the requirements on the power of the local oscillator beam reaching the HgCdTe detector. This power must not be too high, as this will result in damage to the detector. On the other hand, it must be on the required level for optimal heterodyne detection [9].
From the specifications of the SAT HgCdTe detector it can be calculated that the incident beam intensity must be limited to 100 µW, as was depicted in Fig. 2.3. Just in front of the HgCdTe detector, the LO-beam is cut off by a diaphragm to adjust the beam width to the receiver beam. This cutting off also reduces the power approximately with a factor 5. Thus LO beam power after beamsplitter BS3 should then be about 500 µW.
The beamsplitters BS2 and BS3 have been replaced to have the following specifications:

BS2 ZnSe, 1"	BS3 ZnSe, 1"
s-pol, 45°	s-pol, 45°
s1: R=10[illegible],	s1: R=94.7%,
s2: anti reflection	s2: anti reflection

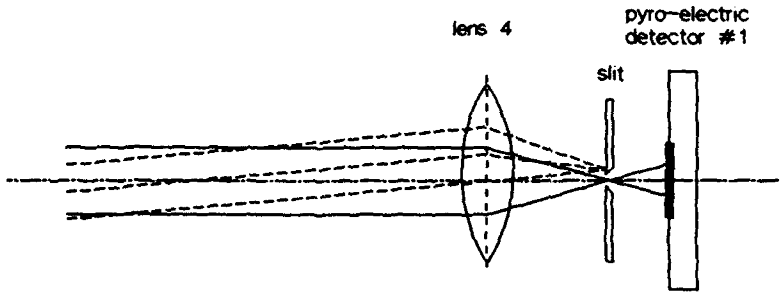


Fig. 2.5 Optical paths through lens L4 and slit.

5) Pyro-electric detector #1, which is used to control the laser stabilization, has a new task in monitoring the laser output.

The angle α by which the beam is deflected by the LO-AOM depends on two factors: the frequency of the AOM driver signal (f_{lo}) and the frequency of the incident laser beam (f_{la}): $\alpha = f_{lo}/f_{la}$. This means that the various laser lines, that can be emitted by the CO_2-laser, will travel along different paths after being deflected by the LO-AOM. The angle of the beams over the laserplatform will differ, and therefore they could miss the HgCdTe detector, whose active surface is only 100 μm in diameter.

Under normal operation the laser is adjusted at the P20-line (wavelength 10.6 μm). In this condition the optics on the laser platform are aligned to focus the local oscillator onto the HgCdTe detector.

It can be calculated that the beams of other laser modes should miss the HgCdTe detector.

In order to assure that the laser is operating in the P20-mode, pyro-electric detector #1 is used to monitor the laser output. For this purpose an accessory is fitted to the detector. It consists of a lens L4 (1", f=25 mm) and a slit (50 μm).

The optical paths through this accessory of the P20 and another laser mode are depicted in Fig. 2.5. If the beam spot in the focus is ≤ 50 μm then all modes except for the P20 laser mode will be blocked by the slit. Thus it should be possible to select the P20 laser mode by just monitoring the signal of pyro-electric detector #1 on an oscilloscope.

It appears that in practice the line selectivity is not very high: beams of several laser modes do pass the slit. However, after setting the slit for the P20 mode, it is still possible to search for the P20 mode. This mode will have the highest beam power, which can be monitored on an oscilloscope with the detector output voltage. So this also proves to be a means of checking, at any time, whether the laser is still stabilized at the P20 line.

6) The former HgCdTe detector was fatally damaged by an unknown cause, in december 1989. The new HgCdTe detector is mounted in a new housing, which also holds the pre-amplifier. The latter is shielded from RF radiation, and located as close as possible to the detector. It is mounted on the existing x-y-z-manipulator that has been rotated 180° around the vertical axis; so the new assembly can still fit in the available space on the laserplatform.

2.2 Changes in the electronics

All changes in the electronics of the set-up are the consequence of the addition of the second acousto-optic modulator in the local oscillator beam (the LO-AOM). Heterodyne detection is no longer performed at a frequency of 100 MHz, but at 140 MHz.

The pre-amplifier, which is located just next to the HgCdTe detector, has been adapted for the processing of the detector signal at 140 MHz. The dynamic range has increased from 50 to 70 dB. As mentioned in section 2.1, the housing of this new pre-amp has also been renewed, for improved shielding of RF-interferences. It is integrated with the holder of the HgCdTe detector for mechanical stability.

A driver for the acousto-optic modulator of the local oscillator has been added. It supplies a 40 MHz sinusoïdal carrier to the transducer. The voltage of the signal can be varied from 0 to 28 Volt by means of two trimpots, labeled *power adj.* and *bias adj.* For optimal operation, set the *power adj.* trimpot to its maximum (fully counterclockwise), and adjust the desired voltage with the *bias adj.* trimpot. As can be checked with an oscilloscope, the driver will than deliver a clean 40 MHz sinoïd. For optimal operation, it is advised to limit the driver output to 20 Volt; a higher voltage will result in distortion of the signal. In the current adjustment the voltage is set to 16 Volt.
The driver has been tested for its frequency stability: in the first 30 minutes of operation the maximum drift was determined to be less than 600 kHz, after this no deviation larger than 100 kHz was observed.

Because the signal processing transceiver needs a carrier of 100 MHz the addition of a mixer was needed. It is placed between the HgCdTe detector pre-amplifier and the transceiver, and mixes the 140 MHz signal down to 100 MHz with the same 40 MHz oscillator that is used for the LO-AOM.

3 OPTICAL ALIGNMENT AND SET-UP ADJUSTMENT

The procedures for the optical alignment can be split up into three parts: the alignment of 1) the transmitter beam, 2) the receiver beam, and 3) the local oscillator beam. The extensive procedures will be discussed in sections 3.1 to 3.3.

Section 3.4 explains the combining of the three beams in order to obtain a good heterodyne detector signal. This co-aligning of the beams can be performed at short range, but should also be conducted at longe range for assuring a perfect parallel course of the beams. Section 3.5 gives the summary of the alignment procedure.

In section 3.6 some additional system adjustments are described. These concern mainly the cooling of various items in the set-up.

During alignment procedures, the use of fluorescence plates is indispensable. These plates will show, when illuminated by a violet lamp, the exact location of the laserbeam. The plates are coded with the numbers 1 to 8, indicating the increasing sensitivity.

In the LF operating mode, the pre-amplifier of the HgCdTe detector enables multiple settings of gain and sensitivity. As the alignment procedure is always guided by the strength of the detector signal, one would want to adjust the pre-amplifier in order to utilise its full dynamic range.

3.1 Transmitter beam.

The beam emanating from the laser is divided by beamsplitter BS1: 76% into the transmitter and 24% into the local oscillator beam. Next the transmitter is directed onto the entrance pipe of the acousto-optic modulator (AOM) by means of two mirrors, M1 and M2.

M1 is mounted on a x-y-manipulator, M2 on a x-y-z-manipulator. Using these the beam can be optimally directed onto the entry lens L1 of the AOM.

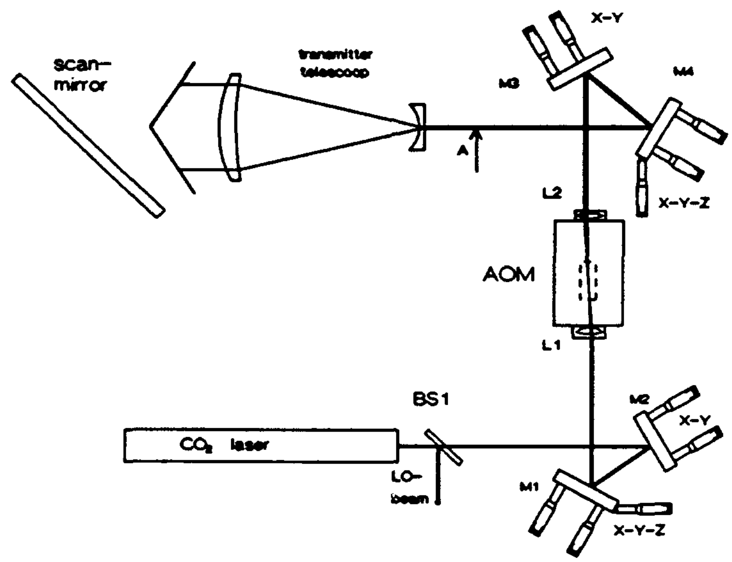


Fig. 2.6 Optical path transmitter beam.

Lens L1 focusses the incident beam in the active part of the AOM-crystal. Once adjusted it should remain aligned. To obtain the maximum AOM refraction efficiency, vary the direction of the laser beam using mirrors M1 and M2, while monitoring the AOM optical output with a power detector at point A, as indicated in Fig. 2.6.

Bentvelsen [5] determined and described experimental formulas that give the relation between movements of the manipulators and the resulting shift of the beam at entry lens L1 of the AOM.

The emanating beam from the AOM passes another lens, L2, which focusses the beam at 0.85 meter; this assures an optimal course of the beam through the pupil of the transmitter telescope when modulated with sinusoïdal signals in the frequency range of 90 to 110 MHz.

Mirrors M3 and M4, are mounted, like M1 and M2, on a x-y- and a x-y-z-manipulator respectively. They direct the beam into the transmitter telescope.

A special diaphragm, 1" diameter, cut in a metal plate and mounted on the correct height functions as a filter when placed in front of the telescope. This assures that only the center spot of the beam will be visible on a fluorescence plate of maximum sensivity.

Switch the AOM voltage selector, located at the side of the laserplatform, to the position marked *high*. Drive the AOM with continuous wave signals of frequencies 90, 100, and 110 MHz, using a RF synthesizer, while not exceeding an input signal level of 0 dBm.
Now the course of the beam can be optimized by mirrors M3 and M4, so that an 100 MHz modulated beam illuminates the fluorescence plate uniformly. The 90 and 110 MHz signals should result in illuminations by the beams that are identical but displaced in opposite direction: one beam will fall upon the plate at the top, and the other at the bottom.
Any irregularity in the lightening of the fluorescence plate indicates a non-straight laser beam course, which should be corrected by mirrors M3 and M4.

For the alignment of the videocamera, or a viewer telescope, with the transmitter beam, the AOM should again be driven with a 100 MHz continuous wave signal. A chopper is placed in the beam between mirror M4 and the telescope. The beam is aimed at a pyro-electric detector placed at some distance, preferably more than several hundreds of meters. The signal from that detector should be available for the adjusting person. At the TNO-FEL laboratory this can be achieved with a combined detector/retroreflector assembly, which is mounted specifically for this purpose onto a "meteo"-tower at 300 meter distance. The detector signal is fed back to the laboratory-site through a coax-cable. The retroreflector will be used in the alignment of the receiver beam, as will be described in section 3.2.
Upon detecting the laser beam, the videocamera and the viewer telescope can be visually adjusted to their correct positions.
At this point the divergence of the transmitter beam can be checked. Moving the scanmirror by one step, using the XY-scanner, should reduce the detector signal somewhat; 3 or 4 half steps should result in a total loss of the signal. One can distinguish between horizontal and vertical movement of the scanmirror.

3.2 Receiver beam.

The alignment of the receiver beam corresponds actually with positioning the HgCdTe detector.
Usually this can be performed in direct succession to the alignment of the transmitter beam as described in section 3.1. Using the detector/retroreflector accessory, which has been mounted onto the Meteo-tower at TNO-FEL, the chopped transmitter beam is reflected back to the set-up, i.e. into the receiver telescope. Like in section 3.1, the AOM modulates the transmitter beam with an 100 MHz CW signal, the AOM driver is switched to *high*. The LF direct-detection signal is

monitored on an oscilloscope. As our chopped signal has a frequency of 30 Hz, it is advised to utilise an oscilloscope module which allows the signal to be bandpass filtered.

Next optimize the HgCdTe detector position for maximum signal output, while maintaining the transmitter beam aimed at the detector/retroreflector.
It is best to start optimizing with the pre-amplifier gain switched to *high* and the *10 kΩ* resistor selected. If any signal is found, the output will start clipping at about 6 Volt, so the gain should now be switched to *low*. At still more signal the input resistance of the pre-amplifier can be reduced to *10 Ω*. In this final stage an output signal of several tens of millivolts should be obtained.
A good check for correct receiver beam course through the receiver telescope can be made when a strong signal is present. By moving a thin plate in front of the receiver telescope, and watching the oscilloscope, one can easily determine *where* the beam enters the telescope, obviously this should be in the centre of the lens.
This is not trivial: during our alignments we encountered two situations where a maximum signal was obtained while the receiver beam entered the telescope at the side of the lens.
First this occurred when the telescope was removed from the laserplatform, and mounted again but rotated 45° or 90°. Apparently the holder *or* the lens is not rotationally symmetric.
The second occurrence was at the replacement of the large telescope lens by another one, which we believed to be identical. It appeared in this way that it was not.

In practice, it can be very difficult to find a detector position that results in any detection signal at all. Whenever this situation arises, for example after a temporary removal of the HgCdTe detector from the laserplatform, an alternative procedure must be followed to find the approximate HgCdTe detector position.
A source of thermal radiation, with a chopper in front of it, is placed at preferably the same distance as the pyro-electric detector was in section 3.1.
The incident infrared radiation is again direct-detected with the HgCdTe detector. It is easier to obtain a signal as this radiation source is stronger, more stable, and omnidirectional, and not suffering from side-lobes like laser beams in practice do. Next the detector position can be optimized for both pre-amp output and beam course through the receiver telescope.
If, after this, the direct-detection of the transmitted laser beam still appears problematic, it is advised to carefully check the course of the *transmitter* beam through its beam expander.

Normally this should not be very difficult, so that the co-alignment of the transmitter and receiver beam can be performed finally by optimizing the HgCdTe detector position.

3.3 Local oscillator beam.

The part of the laser beam that is deflected by beamsplitter BS1 is directed into the LO-AOM by mirror M5. The intensity of this incident beam is about 1 W, as depicted in Fig. 2.7.
The holder of mirror M5 is mounted on the laserplatform with a thin plate underneath it. This plate is not parallel, but introduces an angle of 1°. This reduces the beam height from 60 mm to 50 mm, and the beam incides the LO-AOM under an angle of 38.5 mrad.

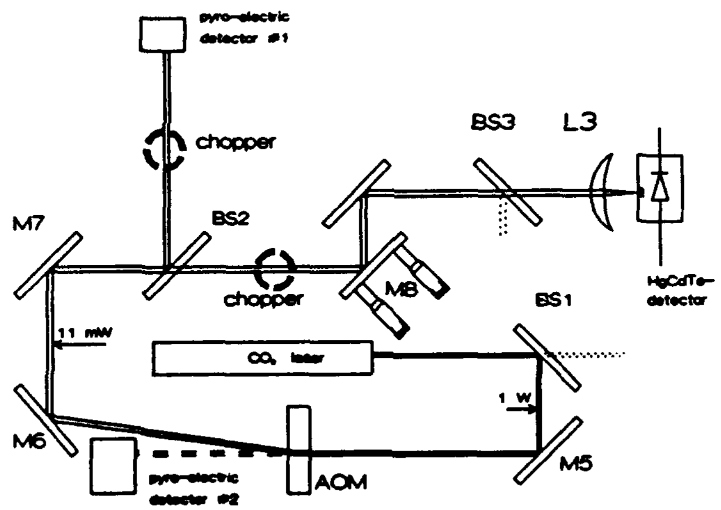


Fig. 2.7 Optical path of the local oscillator beam.

The beam that is transmitted by the LO-AOM (about 98%) reaches the pyro-electric detector #2. It is used for the stabilization of the laser.
The LO-AOM deflects, and shifts in frequency, about 2% of the incident beam, which is in our case approximately 11 mW. This beam is deflected upwards by the LO-AOM by an angle of 77 mrad onto mirror M6, and reaches a height over the laserplatform of 65 mm; all subsequent optical components should not alter this height, so that the beam reaches the HgCdTe detector at the same height as the receiver beam.

Mirror M6 is thus adjusted so that the beam is lead horizontally to mirror M7, which directs it onto beamsplitter BS2.
Here 10% of the beam intensity is reflected to pyro-electric detector #1, which is used to monitor the relative laser output power. As described in section 3.1 the lens L3 and the slit S1 are adjusted as to maximize the detector output when the laser emits the P20 line of wavelength 10.6 μm.
The transmitted 90%, which equals an intensity of around 10 mW, passes to mirror M8, which is mounted in a x-y-z-manipulator. This is the final element that should be used to adjust the fine alignment of the local oscillator beam onto the HgCdTe detector.
The LO beam is directed in the metal housing by mirror M8. It passes four more optical elements, which are fixed in position. These are a mirror, a beamsplitter BS3, a lens L4, and a diaphragm.
The beamsplitter BS3 transmits 5% of the incident LO to the lens L4, which focusses it onto the HgCdTe detector, after the diaphragm has cut off about 80% of the remaining intensity.

Place a chopper in the local oscillator beam, just in front of mirror M8 for optimizing. Follow the procedure for optimizing direct-detection as it was previously described in section 3.2; the LF output signal of the pre-amplifier should again yield:

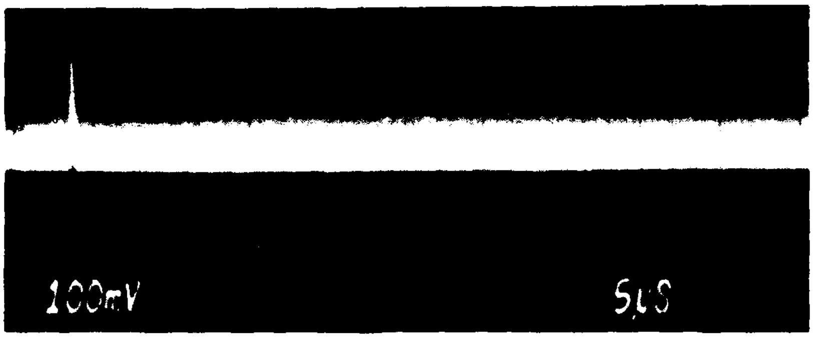
pre-amp: switch: LF detector signal: 2 V
gain = LOW
Z = 10 Ω

One last issue concerns the optical power in the LO. Care should be taken to limit the power in order not to damage the HgCdTe detector. This can easily be achieved by adjusting the LO-AOM driver voltage. As mentioned in section 2.2 this should be performed using the *bias adj.* trimpot.

3.4 Optimization of the heterodyne detection.

Any further adjustments in this stage of the alignment should be performed using just the positioning controls of the HgCdTe detector and mirror M8; the last being an correction of the local oscillator, to let it coïncide with the receiver beam onto the HgCdTe detector.

Set the transceiver in the FM mode; send a single chirp. The transceiver can be triggered either by the HP 9000 computer or by a signal generator connected to the transceiver *ext. trigger in* (front panel).



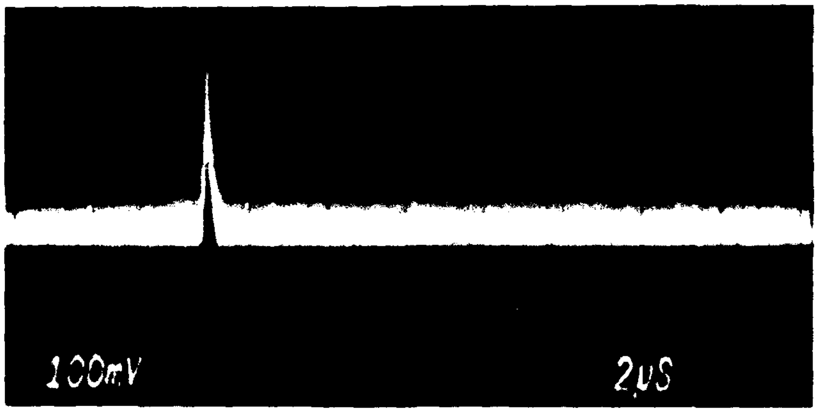


Fig. 2.8 Photographs of oscilloscope with heterodyne noise and signal; a) time base 5 μs, b) 2 μs.

Remove the choppers from the transmitter and local oscillator beams. Set the pre-amplifier to the HF mode using the switch at the side of the laserplatform (next to the connectors at the left side).

Lead the heterodyne detector signal from the transceiver (frontpanel PFM connector) to a 50 Ω input module on the oscilloscope; adjust it to 100 mV and 2 μs per division (or 5 μs/div). The signals which are to be expected are depicted in Fig. 2.8 a and b.
If the transmitter and the local oscillator beams are blocked, the detector signal should yield about 20 mV noise. When the local oscillator passes onto the detector, the detector noise will increase to approximately 100 mV. These simple tests will assure the operator that the set-up is electronically in good working order.

Now remove the block of the transmitter beam. Aim the beam at a target, which is located at the same distance as was used during the alignment procedures of the previous sections. The heterodyne signal peak should be strong enough to yield a signal on the oscilloscope of 0.2 to 1 V, depending on the nature and range of the target on which the laserbeam is aimed. The input LED-bar of the transceiver should indicate the maximum level.

Aim the beam at a target which is located at a large distance, several kilometers at least. The peak in the oscilloscope signal will probably vanish in the heterodyne noise. This indicates that the transmitter and receiver beam are not yet fully aligned to each other due to a parallax effect; in the alignment procedure at short range we focussed the two beams onto one point, the detector/retroreflector.
For example, using the assembly mounted onto the Meteo-tower at the TNO-FEL laboratory, the distance on which we align is 300 m. Knowing that the two beams are separated horizontally by 7 cm as they leave/reach the laserplatform at the scanmirror, it can be calculated that the HgCdTe detector should be shifted 100 μm in horizontal direction to parallel the transmitter and receiver beams. Of course one must also adapt the local oscillator beam to the new detector position.

It is also possible to optimize the co-alignment of the beams manually. Switch the transceiver from auto-gain to manual mode: the heterodyne signal can then be optimized using the input LED bar of the transceiver. Introduce very small variations in the *horizontal* detector position, while immediately adapting the local oscillator using mirror M8.

3.5 Summary of the alignment procedure.

The procedure for optical alignment of the three beams on the laserplatform can be divided in the following steps:

1) **transmitter beam aligned through the AOM.**

2) **transmitter beam aligned through telescope.**

modulation : **CW 90, 100, and 110 MHz**

3) aim for detector/retroreflector assembly, maximize detector signal.

modulation :	CW 100 MHz
chopper :	in transmitter beam

4) adjust camera, and viewer telescope, to detector/retroflector.

5) direct-detection receiver beam, positioning HgCdTe detector.

modulation :	CW 100 MHz
chopper :	in transmitter beam
pre-amplifier :	LF output
oscilloscope :	input impedance module: 1 MΩ
filters:	LF 10 Hz, HF 100 Hz

6) direct-detection local oscillator beam.

modulation :	CW 40 MHz
chopper :	in local oscillator beam
pre-amplifier :	LF output, 10 Ω
oscilloscope :	input impedance module: 1 MΩ
filters:	LF 10 Hz, HF 100 Hz

7) heterodyne detection, co-alignment of transmitter/receiver.

modulation :	CW 100 MHz
LO modulation :	CW 40 MHz
pre-amplifier :	HF output
transceiver :	transmit FM chirp
front panel output:	PFM
oscilloscope :	input impedance module: 50 Ω
	100 mV/div, 2 μs/div

3.6 Additional adjustments.

There are a few non-optical aspects that must be carefully checked and monitored for reliable operation of the system. These consist of the cooling of the CO_2-laser, the AOM in the transmitter beam, and the HgCdTe detector.

1) According to the instruction manual for the Edinburgh Instruments model WL8 CO_2 laser, the temperature of the laser head should be 30°C maximum, for optimal operation. The cooling unit must be able to dissipate 250 W, which requires a minimum flow rate of 2.0 litre per minute. It is important that the temperature of the coolant is constant, as this influences the stability of the laser frequency. In our set-up the coolant temperature is set to 12°C.

2) The acousto-optic modulator in the transmitter beam must also be properly cooled, or permanent damage will occur. As the cooling system is shared with the CO_2-laser, the coolant temperature is also 12°C. As was previously determined and described by Bentvelsen [5], the minimum flow rate through the AOM must be 3 cm^2/s.
The flow rate is constantly being checked by the ETA strömungswächter as a protection for the AOM. Should the flow rate become too low, or too high, then the power to the laser system is cut off. The acceptable upper and lower limits of flow rate must be set by adjusting the corresponding trimpots of the ETA strömungswächter. These should not be set too critical, as this will result in frequent and unnecessary interruption of the laser operation.

3) The HgCdTe detector is designed for operation at a temperature of 77 K, to be cooled with liquid nitrogen.
The dewar in which the detector element is mounted should be filled with liquid nitrogen to a height of several centimeters below the top rim.
If the dewar is filled further this would cool down the dewar sealing ring; this results in diminishment of its sealing properties, and the vacuum of the dewar cannot be sustained for long.
When the level of liquid nitrogen varies over a wide range a noticeable vertical displacement of the HgCdTe detector takes place inside the dewar. It goes without saying that when this occurs it would disturb the alignment of the system.
For the purpose of monitoring the liquid nitrogen level in the dewar, a plastic tube with sensors can be placed into the dewar. The current level is then indicated by a LED-bar at the side of the laserplatform.

It consists, from lowest to highest level, of three red, one orange, four green, another orange, and two red LED's. A safe level is considered when one or more green LED's are alighted. The orange LED's, at either side of the green range, indicate an intermediate filling level; the red LED's imply a level that is either too high or too low.

A system is provided that will monitor the liquid nitrogen level, and takes care of the filling of the dewar automatically. When the level gets too low, a stock of liquid nitrogen in a container under the laserplatform is heated up. This raises the pressure in the container, so that some liquid nitrogen is pumped out into the dewar. The filling stops when the maximum level is reached, as indicated by four illuminated green LED's.

There are two disadvantages to using this system.

First, the liquid nitrogen level will vary between the lowest and highest permitted levels, as indicated by none and four iluminated green LED's. If one refills the dewar manually every fifteen to twenty minutes, the level is easily maintained at a much smaller interval.

Secondly, the automatic filling system can start operating at any moment, which in practice will be during the execution of a measurement. Again if refilling manually, one would do this conveniently between two measurements.

During the measurements described in this report, the automatic refilling system was not used.

4 POSSIBLE SYSTEM MODES FOR MEASURING

As our laserradar system is designed to be multifunctional, there are several possible modes in which measurements can be performed.
The mode is determined by the modulation that is applied to the transmitter laser beam, which is accomplished by driving the AOM with certain signals as generated by the transceiver.
The three implemented possibilities are: 1) frequency modulation (FM), 2) amplitude modulation (AM), and 3) continuous wave (CW). These will be shortly described in the following sections.
A more detailed description of the different modes of modulation has, within the scope of this project, been given by Lerou [1], Van der Vegt [2], and Bentvelsen [4].

4.1 Amplitude modulation.

This type of modulation enables the range of a target to measured.
As was explained by Lerou [3], a pseudo-noise code applied as on/off modulation to the beam can, after time delay by the travel to and from the target, be detected and cross-correlated with the original code. Ideally this will yield a triangular pulse that has a shift from the origin position proportional to the time delay.
One advantage of the AM mode is that a duty cycle of 50% can be obtained.

4.2 Frequency modulation.

This mode enables the determination of both range and velocity of a target.
A pulse is generated that will yield a chirp, after passing a surface acoustic wave device (SAW). This is a signal whose frequency evolves, in our case, from 90 to 110 or from 110 to 90 MHz in 5.5 μs. The AOM modulates the transmitted beam, and the reflected chirp is again processed in the transceiver: a SAW compressor yields a pulse modulated carrier, whose envelope is detected. The time delay since the transmitting is determined, from which the range follows.
To determine the speed of a target as well, both an up-chirp whose frequency shifts from 90 to 110 MHz, and a down-chirp from 110 to 90 MHz, are transmitted. The opposite Doppler frequency shifts in the received chirps yield information regarding the speed of the target.
The main advantage of the FM mode emanates from the process of pulse compression: it results in a better signal to noise ratio.

4.3 Continuous wave.

The third mode in which the system can transmit is continuous wave. The transceiver generates a 100 MHz signal for the AOM.

This mode is extensively used during the alignment of the optical set-up as was described in sections 3.1 through 3.5.

It also has an application in vibration detection measurements. The reflected laser beam is modulated in frequency by the vibrating target. This Doppler information can be recovered by applying FM demodulation in the frequency range of interest: in our experiments the demodulated signal in the range 0 to 1 kHz was recorded onto audio tape, containing the vibration spectrum of a target.

5 CONCLUSIONS

The multifunctional CW CO_2-laserradar has been modified successfully. An acousto-optic modulator has been added into the local oscillator beam path, to improve optical local oscillator isolation. A new HgCdTe detector has been installed in the set-up. Processing electronics have been redesigned, modified and built to accomodate the shift of 100 to 140 MHz in heterodyne detection frequency and also for alignment procedures.

A detailed manual has been presented for the optical alignment of the set-up.

The laserradar, as it is now, performs well in all three operating modes; operational results are reported by Boetz [1] and Hebers [2].

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THE SET-UP OF A MULTIFUNCTIONAL CW CO2-LASERRADAR SYSTEM IS DESCRIBED. SPECIAL ATTENTION IS GIVEN TO SOME RECENT MODIFICATIONS. THEY CONSIST MAINLY OF THE ADDITION OF AN ACOUSTO-OPTIC MODULATOR (AOM) IN THE LOCAL OSCILLATOR BEAM OF THE HETERODYNE DETECTION SYSTEM, AND OF THE RENEWAL OF THE HGCDTE DETECTOR.
THE ADDED AOM SHIFTS THE FREQUENCY, AT WHICH HETERODYNE DETECTION IS PERFORMED, FROM THE PREVIOUS 100 MHZ TO 140 MHZ NOW. THIS IMPLIED THAT THE PROCESSING ELECTRONICS OF THE SET-UP ALSO HAD TO BE ADAPTED.
A STEP BY STEP PROCEDURE FOR THE OPTICAL ALIGNMENT OF THE SYSTEM IS PRESENTED.

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